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Capacity planning and resource allocation in assembly systems consisting of dedicated and reconfigurable lines

Dávid Gyulai[a,b]*, Botond Kádár[a], László Monostori[a,b]

[a]*Fraunhofer Project Center on Production Management and Informatics, Institute for Computer Science and Control, Hungarian Academy of Sciences, H-1111 Budapest, Kende u. 13-17, Hungary*
b Department of Manufacturing Science and Technology, Budapest University of Technology and Economics, H-1111 Budapest, Egry József u. 1. Hungary

* Corresponding author. Tel.: +36-1-279-6176; fax: +36-1-466-7503, *E-mail address*: david.gyulai@sztaki.mta.hu

Abstract

Companies with diverse product portfolio often face capacity planning problems due to the diversity of the products and the fluctuation of the order stream. High volume products can be produced cost-efficiently in dedicated assembly lines, but the assembly of low-volume products in such lines involves high idle times and operation costs. Reconfigurable assembly lines offer reasonable solution for the problem; however, it is still complicated to identify the set of products which are worth to assemble in such a line instead of dedicated ones. In the paper a novel method is introduced that supports the long-term decision to relocate the assembly of a product with decreasing demand from a dedicated to a reconfigurable line, based on the calculated investment and operational costs. In order to handle the complex aspects of the planning problem a new approach is proposed that combines discrete-event simulation and machine learning techniques. The feasibility of the approach is demonstrated through the results of an industrial case study.

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1. Introduction

Capacity management and long-term resource allocation are complex strategic planning tasks in a sense that they have to deal not only with the available production capacities and financial constraints but also need to consider the possible future changes in the order stream and product life-cycles. In general, production planning is a hierarchical process that has three main levels based on the length of planning horizon and level of aggregation. Capacity planning and management is on the strategic level that is based on long-term business goals and market forecasts. The main function of the strategic planning is to decide about the products to be produced and the necessary capacities that are required to fulfill the demands.

In order to meet the customer demands, not only the production process, but also the structure of the production system has to be robust against both internal and external conditions. Dynamic changes of the market environments and high variety in the product portfolio require responsive production systems that are able to react to external changes by the ability of adaptation and robustness [1].

The efficient management of variety in production is one of the greatest challenges in today's industry [2]. Depending on the order volumes of products and the diversity of the product portfolio, different solutions exist to ensure cost-efficient production. The capacity planning method proposed in the paper considers two main types of manufacturing lines, namely dedicated and reconfigurable ones. Dedicated lines are designed around a certain product/product family, and they enable efficient production of large volumes with low product variety. In contrast, reconfigurable lines are suitable to produce a set of different products with high variety in the volumes as well as in the product structure. Naturally, the main drawbacks of the reconfigurable lines are the lower throughput and

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complex planning and control methods necessary to use them efficiently.

Although, both capacity planning and reconfigurable assembly systems (RAS) have broad literature, only few papers consider methods that combine dedicated and reconfigurable lines and dynamic assignment of products to the systems over the planning horizon. In [3] Ceryan and Koren introduce a method that formalizes the capacity planning as an optimization problem based on the flexible premium and determines the optimal resource portfolio for a fixed planning horizon. In [4], [5], [6] and [7] the capacity and system configuration planning process is formulated as a Markovian Decision Problem (MDP) in order to handle the dynamic changes of the order stream and system structure. These methods consider the capacity planning and management as a sequence of decisions on a longer horizon, thus their objective is to find an optimal capacity management policy to minimize costs on the long run. Hon and Xu propose a simulation-based method to optimize the system structure of a reconfigurable system based on the different stages of the products lifecycle [8]. Arafa and ElMaraghy introduce a method that investigates the manufacturing strategy of a firm that faces dynamic market environment, by calculating the volume flexibility of production [9]. Bohnen et al. propose a method for leveling low volume and high mix production based on the identified patterns in the assembly processes [10]. Though, leveling of production is an efficient method to decouple production orders and customer demands, it is more suitable for multi-product assembly lines to minimize the losses caused by the changeovers. In [11], Bruccoleri et al. introduce an agent-based production planning model that considers a multi-level, multi-period decision making process with reconfigurable enterprises and production systems.

In the paper, a novel method is introduced that supports the long-term decision to relocate the assembly of a product with decreasing demand from a dedicated to a reconfigurable line, based on the calculated investment and operational costs. The proposed solution considers two enablers in variety management strategies, planning and manufacturing [2].

The proposed capacity planning method combines discrete-event simulation and machine learning techniques in order to provide a reliable solution in short time. Machine learning-based prediction of dynamic system behavior is applied not only for decreasing the time-consumption planning process caused by the simulation analysis, but also represents an important step towards more complex methods, as for example reinforcement learning (RL). In RL-based formulation of the resource management problem simulation cannot be applied directly, but only as a prediction model of the cost functions.

2. Problem formulation

In the following sections, the considered planning problem is formulated. First the assembly system is introduced that is consisted of reconfigurable and dedicated lines. Then the objective of the capacity management method is stated, namely to reduce the production costs on the long run by assigning the products to the proper type of assembly line. The formulated capacity planning and resource allocation problem is visualized in Fig. 1.

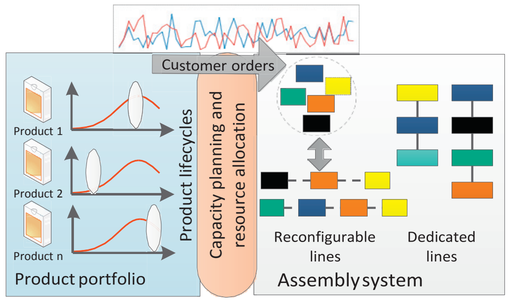

Fig. 1. Illustration of the considered planning problem

2.1. Structure of the considered assembly system

In manufacturing systems that handle diverse product portfolio with both low- and high-volume products, fluctuating production volumes and different stages of products' lifecycle require the regular revision of the production structure applied. In order to minimize the operation and investment costs, effective capacity planning and resource allocation methods are required.

In a preceding publication the authors of the paper proposed a method for replacing dedicated assembly lines with modular reconfigurable ones on the base of standardized assembly processes [12]. The modular reconfigurable lines are set-up by mobile standard workstations based on the sequence of the assembly processes, and they are installed on the shop-floor one after each other by human operators. The dynamic changeability of such a system provides efficient production for low-volume products with high variety. Despite the dynamic behavior of RAS, the necessary resource pool configuration can be estimated based on the order stream and the throughput of the lines can be analyzed by applying discrete event simulation [12].

The goal of the presented capacity planning and resource allocation method is to assign the low- and high-volume products to reconfigurable and dedicated assembly lines respectively, in order to minimize the cost of production in a certain period. In order to determine the optimal set of products that should be assigned to reconfigurable lines, a cost model is defined as it follows.

2.2. Cost model

Although manually operated modular reconfigurable systems offer cost-efficient solution for the production of low-volume products, the investment and operational costs of the system increase significantly with the production volume and also influenced highly by the assigned product mix and production plan. For high volume production, dedicated production systems are applied that have high throughput, high level of automation and thus high investment costs.

In the planning problem, decisions are made in discrete time steps regarding the assignment of the products and necessary investments. The proposed approach applies statistical learning techniques to estimate the costs by predicting the number of machines and the makespan based on the given order volumes (section 3.2). In order to manage the resources consisting of